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# Atmospheric Deposition to Mountain Forest Systems: Workshop Proceedings April 1984

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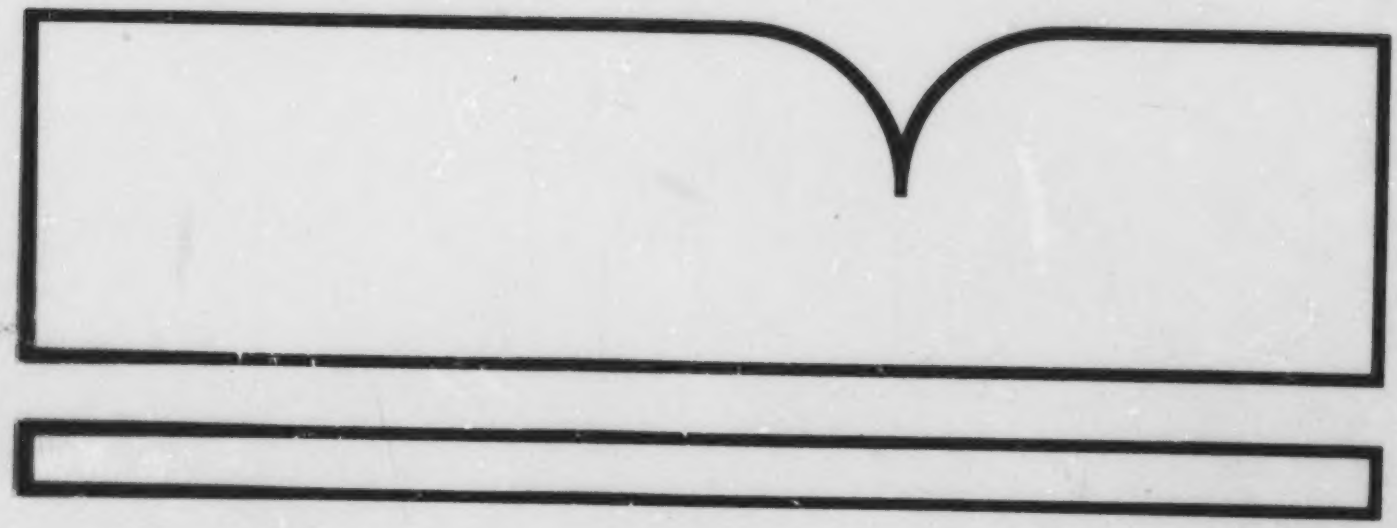

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# ATMOSPHERIC DEPOSITION TO MOUNTAIN FOREST SYSTEMS:

## WORKSHOP PROCEEDINGS
## APRIL 1984

by

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16. ABSTRACT

The Atmospheric Sciences Research Center of the State University of New York-Albany organized and hosted a workshop which specifically addressed the need, design and implementation of research, development and monitoring with advanced techniques for these purposes: (a) to identify the contribution of acidic and non-acidic pollutant deposition to damage of forests on mountain peaks; and (b) to monitor air and cloud chemical quality in regional transport winds for possible source-receptor model evaluation. This report presents the results of the workshop which was held on April 5-7, 1984.

The international aspect of this workshop involved Canadian and European scientists and institutions. The workshop participants recommended the establishment of a research and monitoring network extending from the Smoky Mountains to the Laurentian Mountains where forest and atmospheric scientists can study and test in detail the major hypotheses that have been developed in attempts to explain the current decline of forests.

Recommendations for atmospheric research and monitoring are detailed in this report. They include atmospheric related measurements, deposition related measurements, required meteorological measurements, analytical procedures, and a management structure for coordinating these above activities at the various field sites.

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## PREFACE

The Environmental Protection Agency (EPA) through the National Science Foundation (NSF) has sought the advice and guidance of the scientific community to help with the formation of a long term research program focusing on cloud chemistry in general with special emphasis on the impact of clouds, fog, rime ice and other forms of wet and dry deposition on high elevation mountain ecosystems in eastern North America. NSF has supported fundamental research programs dealing with precipitation chemistry and its impact on ecosystems for the past decade. At this time, the area of interest extends from the Smoky Mountains and the Appalachian Mountains in the southeastern United States to the Laurentian Mountains in Canada, with the Shenandoah Mountains, the Green and the White Mountain ranges, and the Adirondack Mountains in between.

The purpose of this workshop is:

- To present recent evidence of forest damage and hypotheses of cause-and-effect.
- To recommend a specific scientific approach to establish the contribution of atmospheric deposition to mountain forest damage and to monitor long-term trends of air and cloud-water chemical quality.
- To coordinate the workshop participation of U.S. Federal Agencies and private sector research institutes in identifying research needs requiring joint sponsorship.
- Prime candidates to add processes and effects research to EPA's planned atmospheric deposition studies are: the USDA Forest Service, the National Oceanographic and Atmospheric Administration (NOAA), the Tennessee Valley Authority (TVA), the Electric Power Research Institute (EPRI), the National Park Service and others.
- To involve to the Canadian and European scientists and governmental agencies in the recommended mountain ecosystem studies. Candidates for such joint research efforts are the Atmospheric Environment Service-Canada, the Canadian Forest Service, the German Ministry for Environmental Research, and a number of university scientists from these countries.

By combining, coordinating and standardizing the research efforts, methodologies, and instrumentation, and by working cooperatively in determining the causes and character of forest damage in Europe and North America, it is hoped that the overall research efforts will be significantly strengthened.

The Atmospheric Sciences Research Center of the State University of New York at Albany has organized and hosted a workshop which dealt with the above topics. The workshop has specifically addressed the need, design and implementation of research, development and monitoring with advanced techniques for these purposes:

- to identify the contribution of acidic and non-acidic pollutant deposition to damage of forests on mountain peaks, and
- to monitor air and cloud chemical quality in regional transport winds for possible source-receptor model evaluation.

This report presents the results of the workshop, which was held in Albany, NY on April 5-7, 1984 with over 40 invited participants from universities, state and federal government and the private sector.

Following the sponsor's guidelines for this workshop, the report will emphasize mainly the atmospheric sciences component of the overall project. The raison d'être for the studies outlined here are ultimately the ecological impact of atmospheric pollutants on forested ecosystems. Thus it is important to conduct rigorous ecological studies, and to coordinate such studies with studies of atmospheric chemistry and forest meteorology.

In the opinion of the workshop participants this goal can be achieved if the dialogue between forest scientists, atmospheric chemists, meteorologists (in particular forest meteorologists) is strengthened. Additional small work group sessions need now be organized for the purpose of refining and expanding the research tasks presented here and define, in greater detail, the necessary research efforts at the interfaces between the atmosphere and trees and between the trees and soil.

The international aspects of this project involve Canadian and German scientists and institutions. This will greatly enhance the research and information basis of the project. It is hoped that eventually common methodologies, measurement techniques and assessment strategies be used in all three countries. The workshop participants recommend that efforts towards achieving this goal should be continued through appropriate meeting sessions.

## ABSTRACT

The Atmospheric Sciences Research Center of the State University of New York at Albany has organized and hosted a workshop which specifically addressed the need, design and implementation of research, development and monitoring with advanced techniques for these purposes:

- to identify the contribution of acidic and non-acidic pollutant deposition to damage of forests on mountain peaks, and
- to monitor air and cloud chemical quality in regional transport winds for possible source-receptor model evaluation.

This report presents the results of the workshop which was held in Albany, New York, on April 5-7, 1984, with over 40 invited participants from universities, state and federal government and the private sector.

The international aspect of this workshop involved Canadian and European scientists and institutions. The workshop participants recommended the establishment of a research and monitoring network extending from the Smoky Mountains to the Laurentian Mountains where forest and atmospheric scientists can study and test in detail the major hypotheses that have been developed in attempts to explain the current decline of forests.

Recommendations for atmospheric research and monitoring are detailed in this report. They include atmospheric related measurements, deposition related measurements, required meteorological measurements, analytical procedures, and a management structure for coordinating these above activities at the various field sites.

A cost estimate for the recommended study on atmospheric deposition and its impact on high elevation forest systems is also included.

## Acknowledgment

The success of this workshop resulted from the efforts of many individuals. Each of the participants performed in a dedicated and effective manner, which enabled the timely and successful completion of the project. Special thanks are given to the local Organizing Committee; to Drs. Philip Galvin, John Kadlecek and Eugene McLaren; and to the group session leaders, Drs. Robert Schemenauer, Peter Summers and Jerre Wilson. The suggestions and advise from Dr. Chris Bernabo, Executive Director, National Acid Precipitation Assessment Program; Dr. Gary Foley, Director of EPA's Acid Deposition Research Staff; Dr. John Miller of NOAA's Atmospheric Research Laboratory; and Dr. William Sommers of the USDA Forest Service, have been most helpful and are deeply appreciated. I am particularly grateful to Dr. Jack Durham of EPA's Environmental Sciences Research Laboratory, and to Dr. Jarvis Moyers of NSF's Division of Atmospheric Sciences, Atmospheric Chemistry Section, for their continuous interest in and support of our work in its entirety from the planning through the final reporting stage. I can truly say without reservation that this document reports a joint effort reflecting a significant contribution from each participant including their submission of constructive suggestions and comments as part of their review of this final document.

Volker A. Mohnen
Conference Chairman

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## EXECUTIVE SUMMARY

The EPA/NSF workshop on high elevation forest systems was organized to bring together leading representatives of various scientific disciplines for the purpose of developing jointly a comprehensive research plan that would enable an assessment as to what degree atmospheric depositions are responsible for the observed forest changes. The higher frequency of occurrence of forest damage in high elevation versus low elevation forest systems and the higher deposition of pollution related material in eastern North America versus the western parts of the U.S. and Canada suggest that the initial research efforts should focus at this time on the impact of cloud/precipitation elements and certain air pollutants on the forests of the northern and southern Appalachian Mountains extending from the Laurentian to the Smoky Mountains. The participation of Canadian and German scientists in this workshop provides a unique opportunity for adopting a common research and implementation strategy in all three countries.

Climate changes (i.e., drought) alone cannot adequately explain the observed damages to North American and Central European forests. Manmade causes are thus prime suspects. The wet and dry depositions of acidic or acidifying substances, organic and inorganic oxidants, heavy metals, etc., from the atmosphere onto the forest canopy and their subsequent movements into the ecosystem are considered by most scientists as a major process by which forest damage can occur. High elevation mountain ecosystems can experience higher deposition fluxes of pollution related material because of (1) their frequent exposure to clouds, fog, dew or related special deposition processes and, (2) the high wind speeds aloft causing higher collection efficiencies by the canopy.

Four major hypotheses have been developed in attempts to explain the current decline of forests:

- The acidification-aluminum toxicity hypothesis. Increased acidity in the soil leads to increased concentrations of soluble aluminum ions in the soil solution which, in turn, results in accelerated morbidity and/or decreased synthesus of fine feeder roots.

- The general stress hypothesis. "Air pollution" had led to a decrease in net photosynthesis and associated diversion of photosynthesis from mobile carbohydrates to relatively less mobile and toxic secondary metabolites.

- The magnesium deficiency hypothesis. The decline symptoms often occur in combination with extreme magnesium deficiency in trees with plentiful supplies of nitrogen and phosphorous. According to this hypothesis, acid deposition from the atmosphere contributes to the following growth disturbances: it adds nitrogen to the ecosystem but may leach out magnesium and calcium from needles and soils. The leaching from the foliage is presumably accelerated by episodic ozone exposure or frost damage to cuticles and cell membranes.

- The dry deposition air-canopy hypothesis. Ozone and other oxidants (hydrogen peroxide, organic peroxides, nitrogen dioxide, peroxyacetyl-nitrate (PAN)), nitric acid vapor, and sulfur dioxide interact directly with the cuticles and cell membranes of the foliage. During periods of drought, characterized by a high pressure system and air stagnation, the levels of secondary air pollutants (oxidants and acids) can reach episodic levels. Particles containing acids, heavy metals, etc., are also known to cause direct or indirect damage to foliage. The postulated damage could be significantly larger if cloud droplets are intermittently deposited on the leaves or needles, moistening the surface without causing an appreciable "run-off."

The protocols of measurements recommended at this time are intended to help resolve basic research questions, and allow for enough flexibility to both guide and respond to the developments in our understanding of the relationship between depositions and forest response.

The workshop recommends these tasks be carried out by atmospheric scientists to test the multiple working hypotheses outlined above:

- Characterize the variability in wet and dry deposition to the forest canopy.

- Determine the variability of the microclimate.

- Determine loss rates of dominant ions from a watershed.

Atmospheric deposition inputs occur from all three phases (gas, liquid and solid) and actual rates cannot be directly monitored at this time in any of them. Throughfall and stemflow measurements are only relative measures and require knowledge of the ambient, time dependent concentrations of cloud and precipitation water before reactions on the vegetation surface either destroy, create or otherwise modify the species of interest.

The workshop recommends these tasks:

- Monitor cloud water for dominant ions, trace metals and strong oxidants.

- Determine ambient concentrations of selected gases at representative sites--ozone, sulfur dioxide, oxides of nitrogen and, eventually, hydrogen peroxide, ammonia, nitric acid and peroxyacetyl nitrate.

- Determine average chemical composition of aerosol with special emphasis on measuring the ionic concentration of sulfate, nitrate, hydrogen, ammonium and heavy metals.

The measurement efforts toward quantifying atmospheric depositions (cloud and precipitation elements, reactive gases and aerosols) to high elevation forest systems yield an additional benefit. From these measurements it is possible to obtain a representative cloud chemistry data base for the purpose of establishing long term trends, if any, in the ionic composition of cloud water.

The collection and analysis of cloud water--either before or after interception by the forest canopy--at several field sites in eastern North America requires rigorous procedures that must be adhered to by all site operators. To minimize the overall uncertainty of the chemical measurements it is necessary to establish a central facility for analysis of the primary ions contributing to the chemical quality of cloud water. Ideally, this would be the same laboratory that currently is responsible for the NADP/NTN analyses so that interlaboratory bias is eliminated. The use of the Central Analytical Laboratory (CAL) of the NADP/NTN will ensure analysis and quality assurance compatibility between the cloud water and the precipitation chemistry elements of the National Acid Precipitation Assessment Plan.

The Research and Monitoring plan, as described in this workshop report provides the opportunity to conduct highly multidisciplinary research. A great deal of meteorological, air quality, cloud and precipitation quality, forest related and ecological data will be needed to help assess the impact of atmospheric deposition on forest productivity.

Without proper attention to the associated data management issues, the science that could be done would be compromised. Attention, therefore, will be devoted to: (1) information system planning, (2) timely delivery of documented data, (3) standardization and cataloguing, (4) appropriate software practices and, (5) advice from the science community. The best quality science data are produced when the science community is intimately involved in the activity.

The data base management team will provide for:

- Project analysis and reporting by the Project Manager
- Providing comparisons and relationship among data from different project disciplines
- Transfer of the data to a national data base

While existing instruments and methods are adequate to make a useful beginning in measurement of atmospheric deposition into forests, there are some serious limitations in sensitivities for certain species in one or more phases.

Technology limited types of measurement include, for example, gas-phase concentrations of $H_2O_2$, $NH_3$ and organic radicals in clouds or cloud-free air, collection devices for automatically collecting supercooled cloud/fog droplets, and devices for measuring both dry and wet deposition directly to foliage.

A Center for instrument technology is recommended to focus on instrument development and standardization and calibration. The needs for such services are by and large not unique to this program, but common to main-stream problems of atmospheric chemistry, and acid deposition research, so that the work of the Center will be of benefit to, and be cooperative with, that of other groups concerned with atmospheric sampling.

Several regions in eastern North America show evidence of forest species decline. Sites in or near these areas have been selected as appropriate locations to be integrated into a high elevation atmospheric deposition network.

The interactions of the atmospheric-terrestrial system is extremely complicated. Some measurements and commitments of personnel can become fairly expensive. For this reason, it is suggested that sites having primarily one of two slightly different missions be established:

1) monitoring sites to be established for the purpose of providing the data required to test some or all of the hypothesis being considered (at least three such monitoring sites are recommended); and

2) research sites which would additionally provide the facilities and personnel to develop or improve methods for sampling and analysis which will guide the network evolution from a research to a monitoring focus. Three such research sites are recommended for eastern North America.

The recommended field sites are: Mt. Morency, Laurentian Mts.; Mt. Washington, White Mts.; Hubbard Brook, White Mts.; Camels Hump, Green Mts.; Whiteface Mt., Adirondack Mts., Mohonk Mt., Shawangunk Mts.; Shenandoah Mt. (three sites); Mt. Mitchell, S. Appalachian Mts.; Look Rock, Smoky Mts. Site descriptions have been obtained from personnel responsible for each site.

Most important to the successful operation of any site is the availability of local resources of both technical and professional staff. Their commitment to research in the fields of deposition and/or forest ecology must be evident and their work, as judged by their peers, to be of outstanding quality.

Efficiency of operation for a dispersed and sophisticated sampling network of the type recommended here requires an equally efficient and well-integrated communication, decision-making and management system. The recommended research program will include a Management and Assessment Center with a single scientific and technical manager having both the responsibility and authority to carry out this research and monitoring program. It would be responsible only for the U.S. efforts.

The various offices and/or components reporting to the Management and Assessment Center include:

- Cloud Chemistry Research and Monitoring Sites

  a. research sites (total of three are recommended at this time)

  b. monitoring sites (at least three are recommended at this time)

- Meteorological and Climatological Documentation Office for all sites

- Analytical Measurement Laboratory (one centralized facility for all sites)
- Data Management and Quality Control Office (one office for all sites)
- Data Documentation and Distribution Office (one office for all sites)
- Academic Exchange and Minority Program Office (one office coordinating the activities for all sites)
- Center for Advanced Instrumentation Technology (one central facility serving all sites)
- Advisory Committee

The Management and Assessment Center will rely on an advisement committee which will consist of representatives of sponsoring agencies, the site directors, and recognized scientific leaders working in related fields. It will communicate directly with the site directors, who in turn will have full accountability and authority to oversee all activities of the program at their site, in accordance with the management plan worked out in consultation with the advisory committee.

As both government and university policies encourage interaction with small business at appropriate times, cooperation with the small businesses offers this program the opportunity to interact with a wider range of scientists and technicians. Three areas of this program seem appropriate for such interaction: 1) meteorology/climatology, 2) data base management, and 3) instrumentation. Traditionally, these areas have been well developed in the private sector and could offer substantial support to this research effort.

The workshop developed a budget for the recommended activities and a timetable for implementation which includes a phase-in approach. It is anticipated that the proposed research program can be in full operation within three years.

## SECTION 1

## INTRODUCTION

At least one species of trees in high elevation forests has shown a general decline in abundance and display symptoms of dieback at numerous locations in the eastern United States. In the northern Appalachians of New Hampshire, Vermont and New York, this decline has been most noticeable in red spruce in the high elevation spruce-fir forests, less apparent in the lower elevation forests dominated by hardwoods. For example, studies made on Camels Hump, VT, suggest that during the early 1960's red spruce (Picea rubens) began a steady drop in rate of growth (Fig. 1). In about 20 years time average yearly increment dropped by about a factor of four.

Similar effects were occurring on Whiteface Mountain, NY. At Whiteface, 184 stands were surveyed during 1964-1966, 33 of which were resurveyed during 1982. During this period several very significant changes have occurred. The above ground biomass and density of red spruce were lower in all but one of the 21 upland sites (> 900 m) and in all but three of the 12 lowland sites (> 900 m). Upland red spruce biomass had decreased by about 2/3, balsam fir by about 1/3. The decrease in lowland spruce biomass and density was about 1/2. Spruce seedlings were notably absent in high altitude stands, decreasing to one-fifth of their previous frequency; at lower altitudes they had a slight increase in frequency. This suggestion that the spruce decline phenomenon is elevation dependent, is supported by mortality data taken within the northern Appalachians (Fig. 2). At present, the available data do not support a widespread decline in spruce-fir forests in the southern Appalachians, below about 1.9 km elevation. However, very dramatic dieback and decline has been observed at slightly higher elevations, indicating that this problem is not limited to just the northeastern U.S.

During 1983, a survey was performed on Mt. Mitchell, North Carolina. Red spruce above about 1.9 km elevation are displaying severe defoliation and fine root necrosis. Also, no fir, spruce or herbaceous plant reproduction was observed, even though a 1958 vegetation survey observed abundant ground cover at these elevations. These effects seem limited primarily to the higher altitudes, and have, as happened in the northeast, developed over the last two decades. Precipitation records for Mt. Mitchell give no evidence of a drought induced stress occurring during at least the last 30 years. Yet, starting during the early 1960's, both spruce and fir at high elevations show a significant growth rate decline (Fig. 3a) which is not observed at lower elevations (Fig. 3b).

Forest damage, i.e., declines in tree growth and forest dieback, has been widely documented by central European scientists. For example, in Germany a rapidly developing pattern of changes in the appearance and behavior

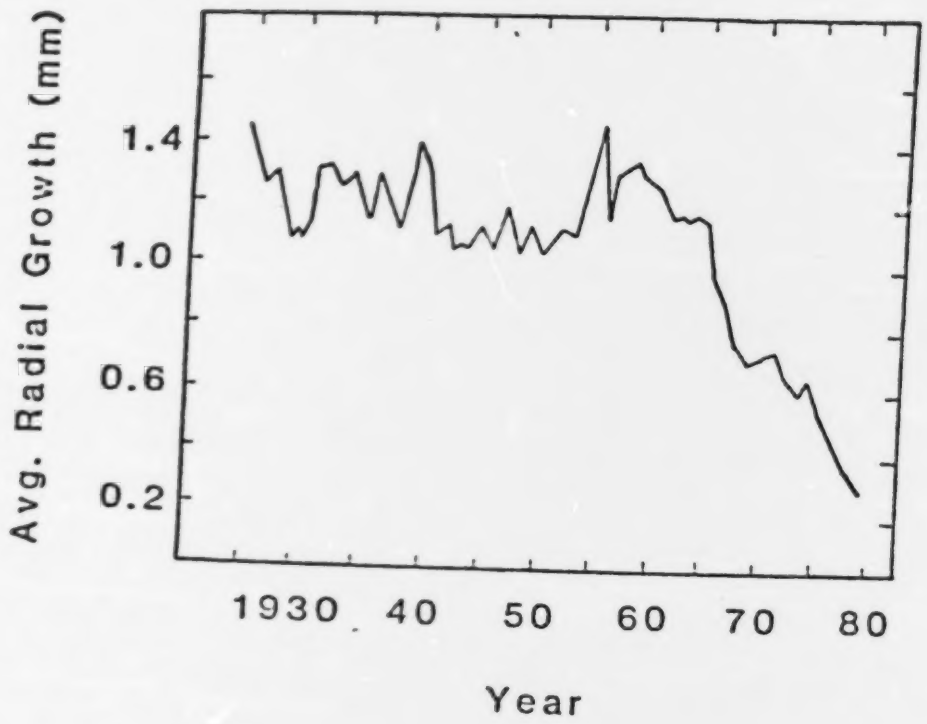


Figure 1. Average radial growth of old (100-220 years) red spruce cored at Camels Hump, VT in 1980. The sample consisted of 10 trees which were declining and in the canopy.
Source: A. Johnson, personal communication, 1984

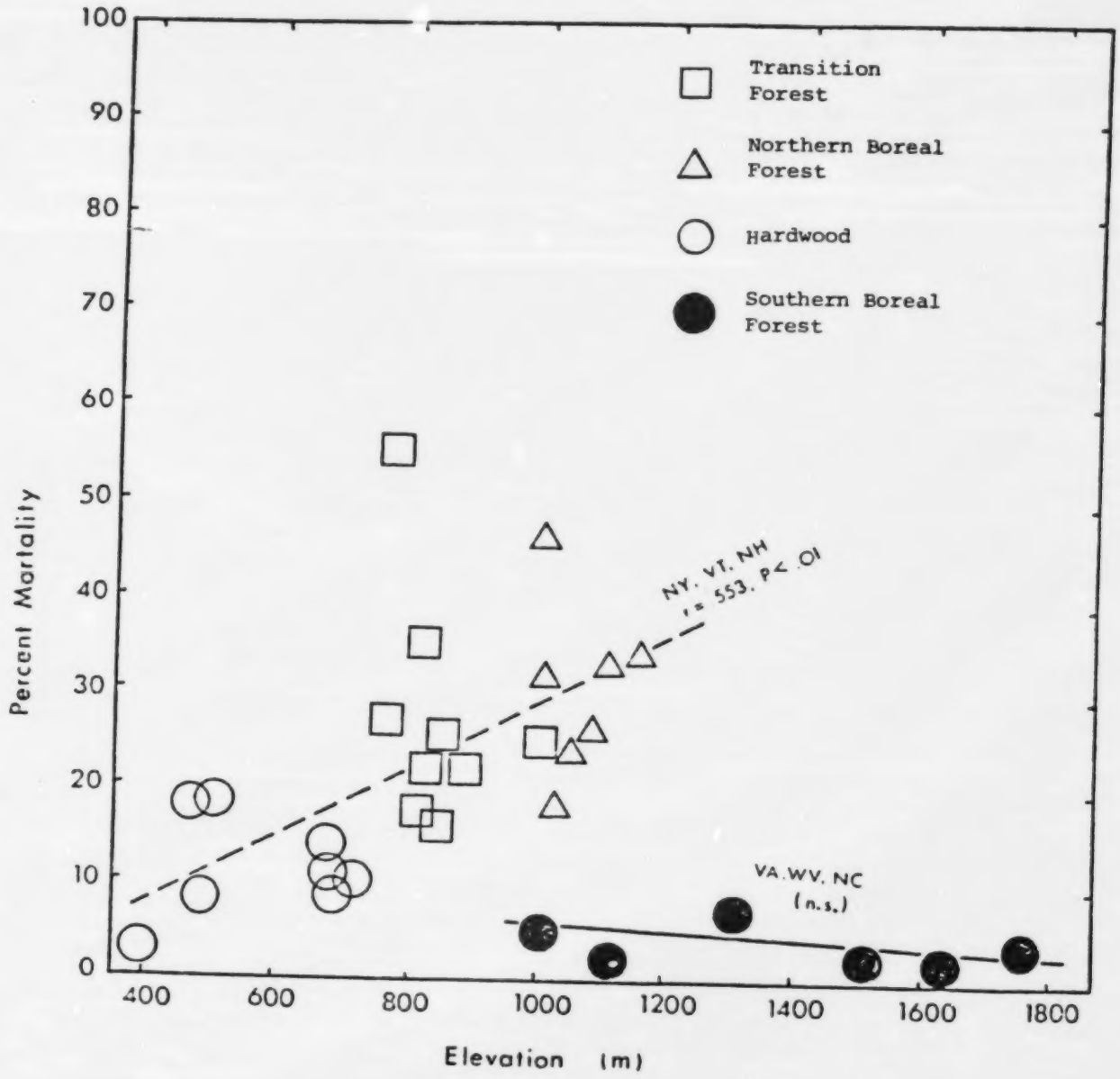


Figure 2. Spruce mortality as a function of elevation in the northern and southern Appalachians.
Source: Johnson and Siccoma, 1983. Environ. Sci. Tech., 17:294A-308A.

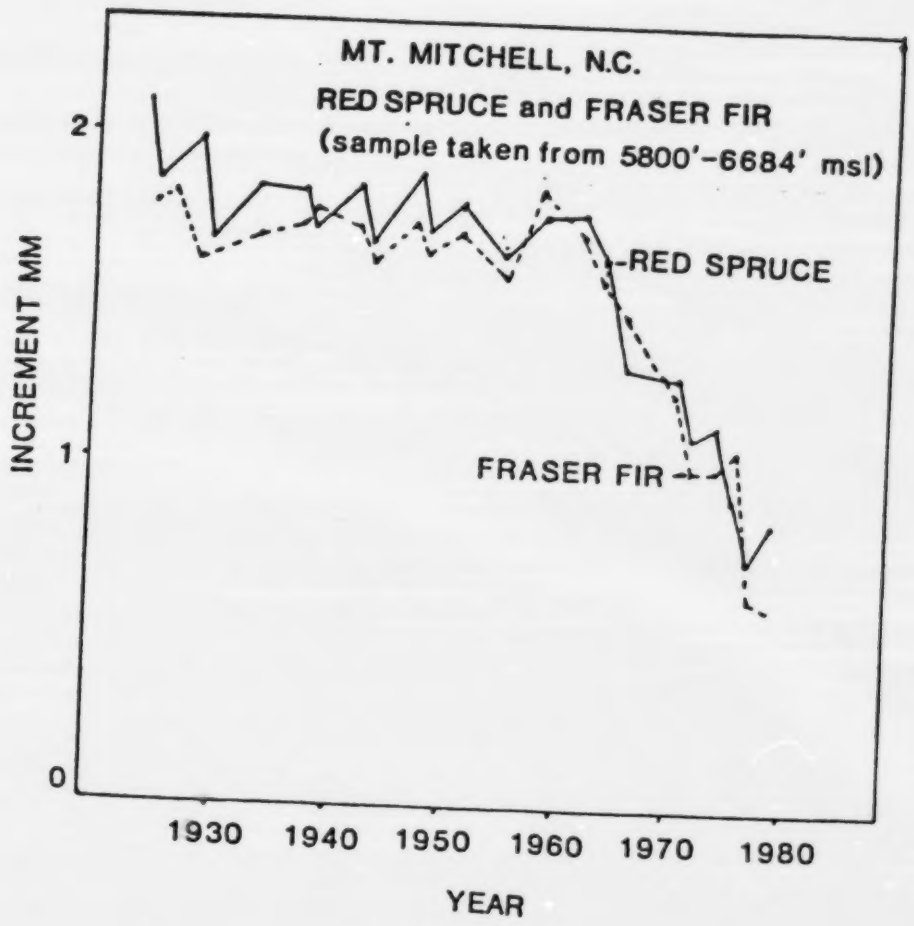


Figure 3a. Mt. Mitchell, N.C., red spruce and fraser fir (sample taken from 5800'-6684' msl)
Source: R. Bruck, personal communication, 1984a

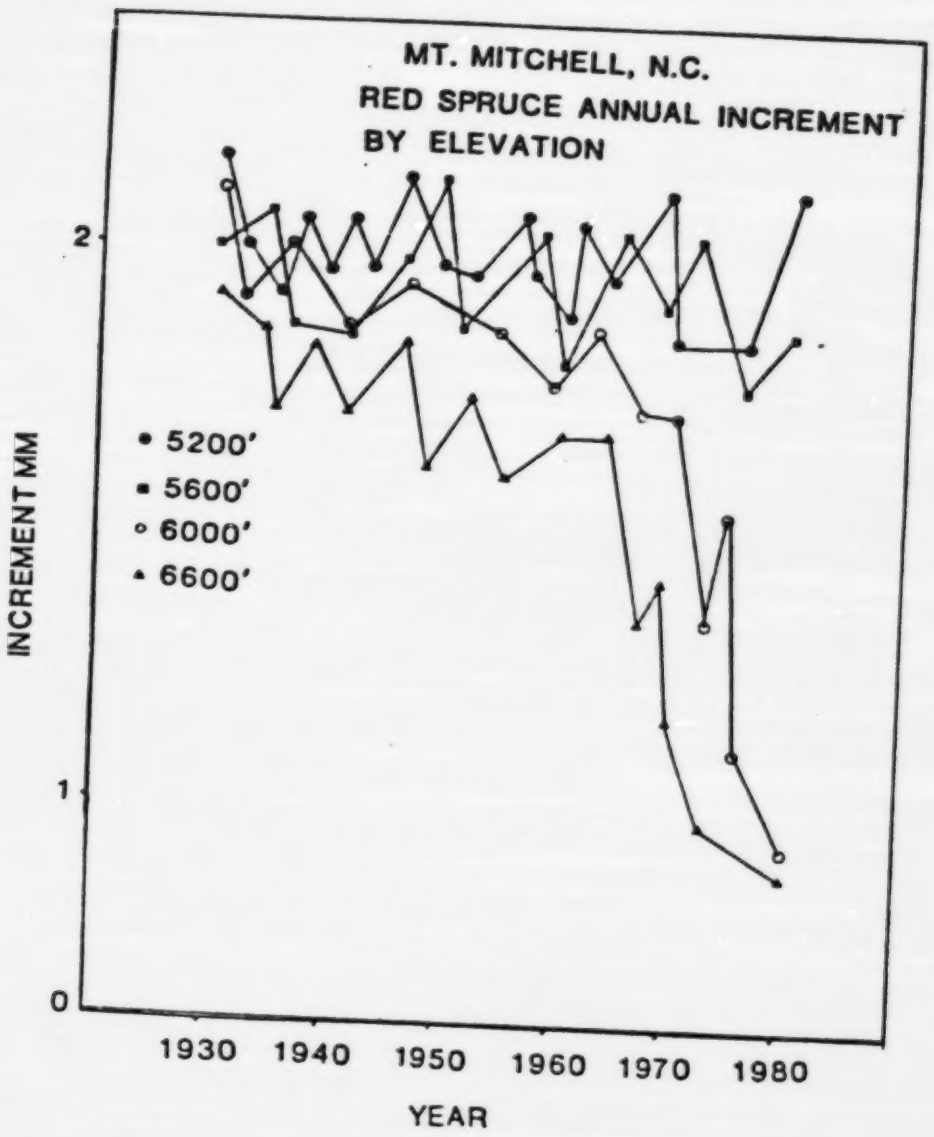


Figure 3b. Mt. Mitchell, N.C., red spruce annual increment by elevation.
Source: R. Bruck, personal communication, 1984b

of forests is observed. The symptoms of decline are not identical in rate or sequence of development in various species of trees or parts of the country. Nevertheless, they include the following features, some of which never or only very rarely have been reported in the literature of forestry or plant pathology: (1) The changes have developed very rapidly and unevenly but roughly simultaneously (since 1979) in many different species and types of forests. (2) The symptoms include a general thinning, change of color, and altered morphology of the leaves and total tree canopy (especially in spruce, fir, beech, and pine), the formation of smaller than normal leaves (especially in beech and spruce), the active casting of green leaves (especially in beech, fir, and spruce), decreased diameter growth (especially in fir during the past 20 years or so, in spruce during the past 10 years, and in beech during the past 5 years). In spruce and fir, the width of annual rings in affected trees has been found to be greater high up on the stem and much less low down on the stem. Unusually large numbers of adventitious shoots are formed on affected spruce and epicormic branches on affected beech trees. The symptoms also include lack of very small numbers of fine feeder roots and mycorrhizae (a symbiotic association of fine roots and beneficial fungi) and discoloration or decreased moisture content of stem and root wood. A Marked deficiency of magnesium has been observed in foliage of affected spruce trees.

This wide array of symptoms has developed (1) very rapidly, (2) on many different species of forest trees (but principally on fir, spruce, beech and pine), (3) in planted forests and naturally regenerated forests, (4) on trees growing on both fertile and infertile soils and both basic and acidic soils (ranging in pH from as low as 3.5 to 8.0), (5) in stands on east-facing, west-facing, north-facing, and south-facing slopes in southern Germany but more commonly on north-west facing slopes in northwestern Germany and on west-facing slopes at elevations above 800 meters in the Black Forest area.

These symptoms have most often been reported in high elevation forests (800-1400 meters). However, essentially similar symptoms also have been observed in forests at moderate (400-800 meters) and even at low elevations. As a result of the alarming trend of forest damage in 1981, the Federal Ministry of Food, Agriculture and Forestry conducted a nationwide damage survey in 1982. The overall result of this first official survey in Germany was that 7.7% of the tree population had been damaged. Detailed figures showed that damages had occurred across the entire country. The low mountain ranges were most heavily affected. A second survey in 1983 found that the amount of damaged forest amounted to 2.5 million hectares, or about 34% of the total forest area throughout the country. The greatest has been to spruce, pine and fir and less to deciduous trees of which beech trees have suffered the most damage.

Climate changes (i.e., drought) alone cannot adequately explain these observed damages to North American and Central European forests. Manmade causes are thus prime suspects. The wet and dry depositions of acidic or acidifying substances, organic and inorganic oxidants, heavy metals, etc., from the atmosphere onto the forest canopy and their subsequent movements into the ecosystem are considered by most scientists as a major process by which forest damage can occur. High elevation mountain ecosystems can

experience higher deposition fluxes of pollution related material because of (1) their frequent exposure to clouds, fog, dew or related special deposition processes and, (2) the high wind speeds aloft causing higher collection efficiencies by the canopy. However, it is a matter of fact that there is no scientific consensus about the causes of the forest damage, even if there is general agreement about the importance of air pollutants.

## SECTION 2

## HYPOTHESES

A comprehensive atmospheric deposition research and monitoring program must have as a final goal the determination of the cause(s) and character(s) of the observed forest changes. Hypotheses have been proposed and experiments must now be designed to test them. The existence of multiple possible explanations imposes a tremendous challenge on the science community that can only be met by establishing multidisciplinary research teams and initiating an iterative dialogue to provide two-way feedback between groups so that the planned joint efforts into atmospheric deposition indiced forest damage can be optimized and fine tuned to each other's needs and capabilities.

Four major hypotheses have been developed in attempts to explain the current decline of forests:

(1) The acidification-aluminum toxicity hypothesis is based mainly on observations below ground. The natural acidification of forest soils is believed to be accelerated as a direct and/or indirect result of deposition of acidic and acidifying substances from the atmosphere. Increased acidity in the soil leads to increased concentrations of soluble aluminum ions in the soil solution which, in turn, results in accelerated morbidity and/or decreased synthesus of fine feeder roots. Lack of feeder roots to increased moisture and nutrient stress and eventually to "drying out" and death of the trees, particularly during periods of drought. The additional deposition of ions due to cloud moisture in high elevation forests will escalate the perceived problem.

(2) The general stress hypothesis is based on field and laboratory observations of symptoms in various tree species. These observations include changes in gas-exchange rates and formation of plant growth hormones and secondary metabolites during symptom development. "Air pollution" had led to a decrease in net photosynthesis and associated diversion of photosynthesis from mobile carbohydrates to relatively less mobile and toxic secondary metabolites. This is turn leads to a poorer energy status in roots and accumulation of toxic substances in shoots which leads to poor development of fine root and mycorrhizae and to foliar decline symptoms. Reduced energy status increases the susceptibility of the trees to other stress factors such as drought cloud moisture, nutrient deficiency, and the usual secondary biotic pathogens.

(3) The magnesium deficiency hypothesis is based primarily on field observations and both soil and foliar chemical analysis in stands of spruce at high elevation. The decline symptoms often occur in combination with extreme magnesium deficiency in trees with plentiful supplies of nitrogen and

phosphorous. According to this hypothesis, acid deposition from the atmosphere contributes to the following growth disturbances: it adds nitrogen to the ecosystem but may leach out magnesium and calcium from needles and soils. The leaching from the foliage is presumably accelerated by episodic ozone exposure or frost damage to cuticles and cell membranes. The magnesium deficiency seems to lead to decreased frost hardiness of the spruce needles. The additional deposition of ions due to cloud moisture in high elevation forests will escalate the perceived problem.

(4) The dry deposition air-canopy hypothesis is based mainly on field observations of ozone and other oxidants (hydrogen peroxide, organic peroxides, nitrogen dioxide, peroxyacetylnitrate (PAN)), nitric acid vapor, and sulfur dioxide interacting directly with the cuticles and cell membranes of the foliage. During periods of drought, characterized by a high pressure system and air stagnation, the levels of secondary air pollutants (oxidants and acids) can reach episodic levels. Particles containing acids, heavy metals, etc., are also known to cause direct or indirect damage to foliage. The postulated damage could be significantly larger if cloud droplets are intermittently deposited on the leaves or needles, moistening the surface without causing an appreciable "run-off."

Because of the heightened interest of forest scientists on this very important issue, it is to be expected that many more hypotheses will be formulated as new observations from the field become available. The general consensus of the science community is to use multiple working hypotheses in the design of a comprehensive field program.

This EPA/NSF workshop on high elevation forest systems was organized to bring together leading representatives of various scientific disciplines for the purpose of developing jointly a comprehensive research plan that would enable an assessment as to what degree atmospheric depositions are responsible for the observed forest changes. The higher frequency of occurrence of forest damage in high elevation versus low elevation forest systems and the higher deposition of pollution related material in eastern North America versus the western parts of the U.S. and Canada suggest that the initial research efforts should focus at this time on the impact of cloud/precipitation elements and certain air pollutants on the forests of the northern and southern Appalachian Mountains extending from the Laurentian to the Smoky Mountains. The participation of Canadian and German scientists in this workshop provides a unique opportunity for adopting a common research and implementation strategy in all three countries.

The following plan of action which evolved from this workshop satisfies the initial information needs of the forest sciences' community. It is intended to test postulated working hypotheses. It reflects the input from all workshop participants representing many disciplines but the approach outlined here only focuses on the tasks to be carried out by the atmospheric scientists. Because of the complexity of the problem, one should expect modifications to this plan as new knowledge is gained in the field by both the atmospheric and the forest scientists.

The essential elements of this plan are:

- Determine the atmospheric deposition of clouds/fog and certain gaseous and particulate air pollutants to high elevation forest systems. In addition to these main efforts, establish a network for obtaining long term representative data on cloud chemistry and related air quality parameters to be used for trend analysis and by modelling community

- Provide meteorological information in support of these field efforts.

- Establish a central analytical laboratory for analyzing cloud water samples from all field sites. (Patterned after the central facilities for processing precipitation samples from existing regional networks.)

- Establish a quality assurance program for this research and monitoring program and determine the accuracy, precision and overall uncertainty of the data obtained.

- Select candidate sites for the study of high elevation forest systems.

- Develop a management structure to support and guide the establishment and timely execution of this multi-site field program. Develop and implement procedures for instrument development and standardization, for quality control, for data dissemination and assessment. Allow for the exchange of researchers and students from the various field sites in North America and eventually from Europe. Solicit the participation of groups from small business and from minorities.

These essential program elements and other related tasks are summarized next and presented in greater detail in the following chapters.

## SECTION 3

## RECOMMENDATIONS FOR ATMOSPHERIC RESEARCH AND MONITORING

Of primary interest to agencies responsible for stewardship of forests and environment in general is the assessment of the impacts of atmospheric depositions on high elevation forest systems: gases, liquids and solids deposited from the atmosphere for a largely undetermined and unstudied effect on numerous components of forest ecosystems. Knowledge is lacking concerning the type and quantity of materials deposited--how they enter the forest ecosystem--the depositional mechanics involved--and the effect of atmospheric processes on distributions of materials in the ecosystem after they are deposited. The potential of impacts of concern thus relate to:

- the ecology and productivity of forests
- the susceptibility of forest vegetation to insects, diseases and environmental stress
- the nutrient cycling within forest ecosystems

No single research program--ambitious as it might be--can address all of these critical problems. In fact, the methodologies on how to attack these research problems are still under development. It is, therefore, of utmost importance for the atmospheric and forest sciences communities to join hands in the design of studies that will lead to a better understanding of high elevation forest systems.

The collaboration between atmospheric and forest scientists has not yet resulted in the development of a research plan detailing every single experimental step that needs to be taken to test the established working hypothesis. However, there is a general consensus between the two research communities on how to proceed. The initial focus of the atmospheric scientists must be on the description of atmospheric deposition and related meteorological support data. The atmospheric related measurements are intended to characterize the chemical species-dependent deposition over time scales judged to be important to the dose-response relation being investigation. Based on the general hypothesis to explain the dieback and declines in tree growth both in Germany and in North America, the ionic, elemental and air quality parameters summarized in Table 1 need to be measured. In addition, the cloud and precipitation water collected both in open areas and within the forest canopy will be analyzed according to procedures established by the high quality precipitation chemistry networks now in existence. Table 1 lists eight potential causes of stress to high elevation forests that have been identified by the workshop. The research program will be constructed to obtain the appropriate field data to test the possibility that observed forest declines can be

TABLE 1. POTENTIAL CAUSES OF STRESS

| Potential deposition-induced stress | Species to be monitored | Time scale |
|---|---|---|
| 1) Aℓ TOXICITY | $H^+$ in deposition | Accumulation over year |
| | $H^+$ and Aℓ in soil solution (using standard techniques of soil analysis) | Follow seasonal changes |
| 2) EFFECTS ON GROWTH REGULATING HORMONES AND GENERAL STRESS | Aerosol deposition (initially using conc. method but ultimately using actual surfaces for collection) and precipitation for inorganic ions (by I.C.) | Event |
| | Oxidants (see 4) | Hours |
| | $SO_2$ | Hours |
| | Metals (by AA, i.e., Pb, Mn, Fe, Zn, Cd, Mg, Ca, Na, K, Hg, Cu) | Event - weeks |
| | $H^+$ | Hours |
| 3) Mg DEFICIENCY | $H^+$ wet, aerosol acidity and nitric acid vapor | Event |
| | Oxidants (see 4) | Hours |
| 4) OXIDANT INJURY | $O_3$, $H_2O_2$, PAN | Hours |
| 5) EXCESS N | N deposition wet (speciation by I.C.) and $NH_3$, $HNO_3$, $NO_x$ | Event - seasonal accumulation |
| | N in soil solution ($NH_4^+$ and $NO_3^-$ by I.C.) | Event |
| 6) CHANGES IN PHYSIOLOGY | Canopy surface - HC, Oxidants, $H^+$ (wet) | Hours |

TABLE 1 (Continued)

| Potential deposition-induced stress | Species to be monitored | Time scale |
|---|---|---|
| 7) METAL TOXICITY | Heavy metals (by AA, i.e., Pb, V, Hg) | Accumulation over years |
| 8) FOLIAR LEACHING | $H^+$, $SO_4^=$, $NO_3^-$, $NH_4^+$, $K^+$, $Mg^{++}$, $Ca^{++}$ in throughfall (by I.C.) | Event |

caused by any of these deposition-induced stresses. Also shown are the species to be monitored and the time scale resolutions needed to develop relationships between the species input rates to the system and its response. Table 1 does not take into account that some of the methodologies to relate atmospheric concentrations to uptake by the canopy are still in the developmental stages. The integration of the atmospheric studies with the forest studies presents a significant research challenge to both scientific communities, yet it is essential for the success of the overall study. How atmospheric deposition might be linked through the 8 major hypotheses to forest damage is shown in the flow diagram in Fig. 4.

The protocols of measurements suggested at this time are intended to help resolve basic research questions, and should allow for enough flexibility to both guide and respond to the developments in our understanding of the relationship between depositions and forest response.

The workshop recommends these tasks be carried out by atmospheric scientists to test the multiple working hypotheses outlined earlier:

- Characterize the variability in wet and dry deposition to the forest canopy.

  The variables to be investigated include elevation above and below cloud base, direction (east vs. west) and aspect (southerly vs. northerly). Throughfall and stemflow will be monitored for each cloud and precipitation event. Initially, eight locations on a mountain will be selected for the monitoring of the site variables mentioned above.

  As the project develops, it should not be necessary to maintain all collections at each site. After the relative depositions at each season become established, the number of active collection sites would be reduced to those capable of providing the most useful information to support the needs of the effects research efforts (testing or hypothesis). Every effort will be made to protect the sample integrity between collection and analysis by minimizing the field exposure time, making field analysis as soon as possible, refrigeration of collected samples, and use of biocides where necessary.

- Determine the variability of the microclimate.

  An essential part of the site characterization is the microclimate influencing the activity of the tree. The variables of interest are temperature (air and soil), relative humidity, cloud liquid-water flux, and snow depth. When the number of active sites is reduced to the key research ones, measures of the biomass activity will be added.

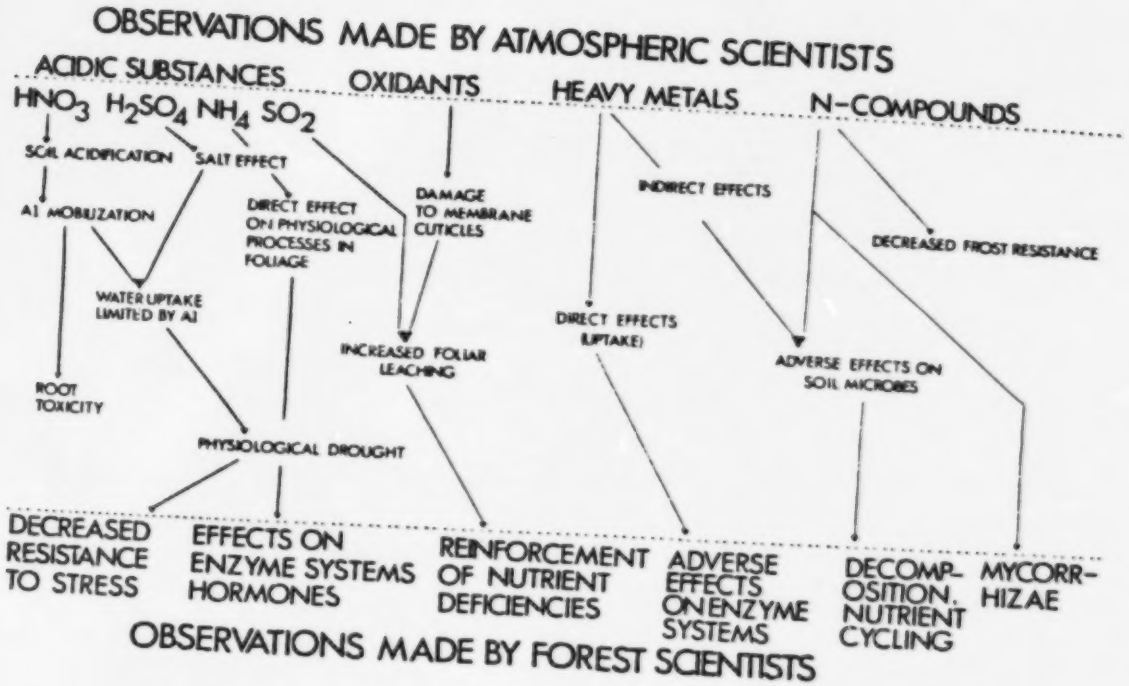


Figure 4. Hypothesized integration of the atmospheric studies with the forest studies. (Source: A. Johnson, personal communication, 1984b)

- Determine loss rates of dominant ions from a watershed.

  This is not intended as a nutrient cycling experiment, rather as a guide to identifying relationships between deposition rates and loss rates in stream flow. However, such studies should not become a major part of the project such that is specifically would control the location of proposed study.

Atmospheric deposition inputs occur from all three phases (gas, liquid and solid) and actual rates cannot be directly monitored at this time in any of them. Throughfall and stemflow measurements are only relative measures and require knowledge of the ambient, time dependent concentrations of cloud and precipitation water before reactions on the vegetation surface either destroy, create or otherwise modify the species of interest.

Direct interaction of gaseous species with the forest canopy are extremely difficult to assess at this time but methodologies should be developed as part of this project to relate atmospheric concentrations to uptake by the canopy.

The workshop recommends these tasks:

- Monitor cloud water for dominant ions, trace metals and strong oxidants.

- Determine ambient concentrations of selected gases at representative sites--ozone, sulfur dioxide, oxides of nitrogen and, eventually, hydrogen peroxide, ammonia, nitric acid and peroxyacetyl nitrate.

- Determine average chemical composition of aerosol with special emphasis on measuring the ionic concentration of sulfate, nitrate, hydrogen, ammonium and heavy metals.

Several important contributions are anticipated that this program will make to acid deposition model development and testing efforts. However, it is difficult to foresee specifically at this time how the expected data could be used to evaluate the performance of models. There is an obvious need to evaluate the new generation of Eulerian regional acid deposition models in a quantitative sense, but there presently exists no concrete operational procedures. Therefore, it would be more constructive for this program to tentatively table this aspect of data base need until the modeling community issues definitive guidelines. At a minimum, modellers could benefit from this research and monitoring program in the following ways:

- One of the crucial data needs is information to assist in the construction of three-dimensional chemical species profiles for model initialization. Vertical profiles of trace species for acid deposition studies are quite scarce. The high mountain observations coupled with intermountain aircraft vertical profiling flights would fill a critical data gap especially if a quality control and intercalibration program is vigorously established.

- In addition to the initialization process, this kind of data can be used qualitatively, and may even be semi-quantitatively useful in evaluating the performance of diagnostic models. Data are needed to test the representativeness of upper-air chemical species partitions and relative abundances. Results from this kind of performance evaluation are invaluable in continuing model improvements.

- The proposed long-term trend observational program will be very useful to all future modeling efforts. All models use observed meteorological data bases in some manner. Good quality chemical species concentration trends at several locations would be very useful for the study of interannual variability of atmospheric chemical processes.

- The proposed data base certainly can help evaluate, and in this case may even help to "validate," scavenging submodules currently under development which will eventually be incorporated into acid deposition models. In contrast to the full regional acid deposition model, a scavenging submodule is being designed to simulate individual scavenging events with detailed accounting of micro-physical processes. Further, the scientific knowledge gained through this observation program will assist the modeling community in parameterizing this essential process in acid deposition studies.

Clearly, as programs evolve it will be possible to identify more areas of useful exchange and revise and amplify some of the existing ideas.

The measurement efforts toward quantifying atmospheric depositions (cloud and precipitation elements, reactive gases and aerosols) to high elevation forest systems yield an additional benefit. From these measurements it is possible to obtain a representative cloud chemistry data base for the purpose of establishing long term trends, if any, in the ionic composition of cloud water.

## SECTION 4

## REQUIRED METEOROLOGICAL MEASUREMENTS

A description of the meteorological and synoptic situation should be an integral part of this research and monitoring program.

Table 2 illustrates the concept for meteorological monitoring at a research and monitoring station. All sites will be equipped to routinely monitor the common atmospheric parameters of temperature, wind speed and direction, humidity, pressure, precipitation, global radiation and dewfall. The research sites will be equipped with a base station as well as a mobile station to characterize the local meteorology.

The main difference in the meteorological instrumentation between the research and monitoring sites is in measurement of cloud characteristics. The research sites will be fully equipped with Forward Scattering Spectrometer Probes and hot-wire probes to describe liquid water content and cloud drop spectra while the monitoring sites will utilize the hot-wire probe only. Additionally, the research sites will be equipped with an automated method for determination of cloud base. This will be accomplished through the use of either a laser ceilometer or a K-band radar. Observer reports and video cameras will be utilized at both type sites to determine cloud base.

These meteorological data will be collected daily and archived. Storage will be accomplished using a compatible data base management with that of the chemistry data. These data will be used to provide site-specific meteorological analysis to assist in the interpretation of cloud and precipitation chemistry data. These data sets will also be used to assist in classifying particular events or sub-events. Some of this will be done in real-time while most will be a post-analysis. Air mass trajectory calculations will also be used to assist in the event characterization process.

TABLE 2. METEOROLOGICAL MEASUREMENTS FOR THE PROPOSED RESEARCH AND MONITORING STATIONS

A) Basic Meteorological Variables

Temperature, wind speed, wind direction, humidity, pressure, precipitation, global radiation, and dewfall

B) Clouds

| | | Research Station | Monitoring Station |
|---|---|---|---|
| 1) | liquid water content | FSSP, CSIRO | CSIRO |
| 2) | cloud base | laser ceilometer/K-band radar<br>observer reports<br>video cameras | observer reports<br>video cameras |
| 3) | cloud droplet spectra | FSSP | |

FSSP - Forward Scattering Spectrometer Probe

CSIRO - hot wire cloud probe

## SECTION V

## REQUIRED ANALYTICAL MEASUREMENTS

The collection and analysis of cloud water--either before or after interception by the forest canopy--at several field sites in eastern North America requires rigorous procedures that must be adhered to by all site operators. To minimize the overall uncertainty of the chemical measurements it is necessary to establish a central facility for analysis of the primary ions contributing to the chemical quality of cloud water. Ideally, this would be the same laboratory that currently is responsible for the NADP/NTN analyses so that interlaboratory bias is eliminated. The use of the Central Analytical Laboratory (CAL) of the NADP/NTN will ensure analysis and quality assurance compatibility between the cloud water and the precipitation chemistry elements of the National Acid Precipitation Assessment Plan. A central facility does not eliminate, however, the need for on site measurement capabilities. At least a few laboratories should have the capability for analyzing liquid cloud water immediately after collection. Since it is of interest to measure additional dissolved materials not yet done at CAL, i.e., heavy metals and certain organic materials, such on site analysis is mandatory. Furthermore, the investigators at a field site might need, for certain projects, an instantaneous check on the collected water samples. Because of the instability of some of the dissolved material such as hydrogen peroxide or dissolved organic compounds (i.e., formaldehyde or weak organic acids) it is mandatory to establish at each site a protocol for sample treatment and initial measurements to be done.

## SECTION 6

## DATA MANAGEMENT AND DISTRIBUTION

The Research and Monitoring plan, as described in this workshop report provides the opportunity to conduct highly multidisciplinary research. A great deal of meteorological, air quality, cloud and precipitation quality, forest related and ecological data will be needed to help assess the impact of atmospheric deposition on forest productivity.

Without proper attention to the associated data management issues, the science that could be done would be compromised. Attention must be devoted to, (1) information system planning, (2) timely delivery of documented data, (3) standardization and cataloguing, (4) appropriate software practices and, (5) advice from the science community. The best quality science data are produced when the science community is intimately involved in the activity. From a scientists's point of view, the following requirements should therefore be levied on the information system:

1) data preprocessing and delivery. The concern here is to assure that quality data (documented) are delivered to the data base. The data could be preprocessed to remove transmission errors and instrument-dependent aspects of the signals. The requirement is that the "scientist" responsible for the "measurement" maintains control over the preprocessing steps.

2) data archives. This deals with an area that must receive considerable attention if we are to fully exploit the data as a resource for the scientific community. Appropriate care should be given to making sure that the data are placed in a long term archive, that documentation is included, that appropriate calibration files are included and that the data are accessible in an efficient way by those in the science community. The data should be accessible by either location or by time of acquisition. The procedure for accessing correlative data acquired by NTN, MAP3S, CANSAP, or other high quality precipitation sampling and analysis networks will be negotiated. In sum, the data base management aspects are crucial areas that would severely hinder the science if not implemented in a reasonable way.

3) interactive scientific data processing. The requirement here is to match the computational requirements with the user needs. This match has not always been given proper attention in the past. The multidisciplinary nature of the science opportunities provided by this research and monitoring program would suggest that previously separate science communities would have to work cooperatively.

Thus, the data base management team will provide for:

- Project analysis and reporting by the Project Manager
- Providing comparisons and relationship among data from different project disciplines
- Transfer of the data to a national data base

## SECTION 7

## CENTER FOR INSTRUMENT TECHNOLOGY

While existing instruments and methods are adequate to make a useful beginning in measurement of atmospheric deposition into forests, there are some serious limitations in sensitivities for certain species in one or more phases. The lack of sufficient sensitivity results in inability to obtain some kinds of data as well as uncertainty in the interpretation of other kinds, particularly within the canopy where interactive processes can cause variations in bulk atmospheric parameters. Technology limited types of measurement include, for example, gas-phase concentrations of $H_2O_2$, $NH_3$ and organic radicals in clouds or cloud-free air, collection devices for automatically collecting supercooled cloud/fog droplets, and devices for measuring both dry and wet deposition directly to foliage.

In addition to the technological development activities of the Center, it will also serve primary functions for instrument repair, calibration and standardization of methods of usage. The intelligent comparison of data from various sites requires a central facility to ensure that identical sensors are used in identical ways. Development of intercalibration procedures, protocols for conditions and methods for instrument usage, and maintenance of a supply of identical parts and/or replacement/loan instruments are ways in which the Center will work toward that goal.

The Center will be aware of the instrument needs of stations in this program as well as the availability and capability of laboratory and commercial instruments. It will endeavor to make sure that transfer of the most recent technology takes place from the laboratory to the field program when needed; and to perform itself or initiate with others the work required to satisfy the station sampling needs. These needs are by and large not unique to this program, but common to main-stream problems of atmospheric chemistry, and acid deposition research, so that the work of the Center will be of benefit to, and be cooperative with, that of other groups concerned with atmospheric sampling.

## SECTION 8

## FIELD SITES

### SELECTION OF MOUNTAIN SITES

Several regions in eastern North America show evidence of forest species decline. Sites in or near these areas have been selected for further review as appropriate locations to be integrated into a high elevation atmospheric deposition network. Among the considerations are:

1) remoteness from local source contamination

2) good access throughout the year to summit and deposition sites on the mountain

3) adequate power where needed

4) availability of historical soil composition data, forest growth pattern and meteorological monitoring data

The list of sites now being reviewed is shown in Table 3. Site descriptions have been obtained from personnel responsible for each site. The included responses to the four considerations mentioned above, along with descriptions of any current research activities of interest to this program.

Most important to the successful operation of any site is the availability of local resources of both technical and professional staff. Their commitment to research in the fields of deposition and/or forest ecology must be evident and their work, as judged by their peers, to be of outstanding quality.

### START-UP OF NETWORK SITES

The interactions of the atmospheric-terrestrial system is extremely complicated. Some measurements and commitments of personnel can become fairly expensive. For this reason, it is suggested that sites having primarily one of two slightly different missions be established:

1) monitoring sites to be established for the purpose of providing the data required to test some or all of the hypotheses being considered; and

TABLE 3. HIGH ELEVATION FIELD STIES CONSIDERED BY THIS WORKSHOP BECAUSE OF THE UNIQUENESS OF THEIR ECOLOGICAL SETTING

| Identification and Region | Previous Record of: Forest Ecology | Cloud Chemistry | NTN Station | Deposition Studies | Meteorological Measurements | Air Quality | Accessibility and Accommodations | Power |
|---|---|---|---|---|---|---|---|---|
| MT. MORENCY Laurentians Mtns. | Yes | No | Yes | Yes | Yes | Minimal | Paved Road Laboratory and Living Quarters | at main station |
| MT. WASHINGTON, White Mtns. | Yes | Yes | No | Yes | Yes | Yes | Paved Road Laboratory and Living Quarters | at main station |
| HUBBARD BROOK, White Mtns. | Yes | Yes | Yes | Yes | Yes | Minimal | Paved Road Laboratory and Living Quarters | at main station |
| CAMELS HUMP, Green Mtn. | Yes | Yes | No | Yes | Minimal | No | Limited Access, no buildings | No |
| WHITEFACE MTN., Adirondacks | Yes | Yes | Yes | Yes | Yes | Yes | Paved Road Laboratory and Living Quarters | at main station |
| MOHONK MT. Shawangunk Mtn. | Yes | No | No | No | Temperature and R.H. | No | Paved Road Laboratory and Living Quarters | at main station |
| SHENANDOAH MTN. 3 sites | Yes | Minimal | Yes | Yes | Yes | Minimal | Paved Road Laboratory and Living Quarters | at main station |

TABLE 3 (Continued)

| Identification and Region | Previous Record of: Forest Ecology | Cloud Chemistry | NTN Station | Deposition Studies | Meteorological Measurements | Air Quality | Accessibility and Accommodations | Power |
|---|---|---|---|---|---|---|---|---|
| MT. MITCHELL S. Appalachians | Yes | No | near by | No | Yes | No | Road | at main station |
| LOOK ROCK, Smoky Mtn. | Yes | No | No | Available near by | Yes | Yes | Paved Road Laboratory and Living Quarters | at main station |

In general, the availability of existing data on forest damage specifically and the state of the forest in general will be a major criterion for selecting research/monitoring sites for this project. The above listing of sites should therefore be viewed as excellent and/or representative examples, but not as a final selection to the exclusion of other potential sites not listed here.

2) research sites which would additionally provide the facilities and personnel to develop or improve methods for sampling and analysis which will guide the network evolution from a research to a monitoring focus. Three such research sites are suggested for eastern North America.

It will not be possible to have all sites begin full operation immediately upon the start of the research and monitoring program. A phase-in time for each site will be set up to accommodate the kinds and intensity of measurements proposed and the training needs of the site personnel. These times should take from about one-half to two years depending on the site. Also, during the start-up time, it will not be appropriate to attempt to monitor every event throughout the year. As technology and sampling needs become better defined, the network management will establish protocols for each site so that with the resources available, the necessary sampling can be done.

## SECTION 9

## MANAGEMENT

Efficiency of operation for a dispersed and sophisticated sampling network of the type envisioned here requires an equally efficient and well-integrated communication, decision-making and management system. The management structure described here has been designed to satisfy these requirements. It includes a centralized management with a single scientific and technical manager with both the responsibility and authority to carry out this research and monitoring program. This Management Center would be responsible only for the U.S. efforts.

The Management and Assessment Center requires the leadership and expertise to enable it to address the demanding technical issues which combine research results with quantitative assessments of the impact of atmospheric depositions on the forest systems under study. It will rely heavily on an advisement committee which will consist of representatives of sponsoring agencies, the site directors, and recognized scientific leaders working in related fields. The planned total number of committee members will be fewer than ten.

The Management and Assessment Center will communicate directly with the site directors, who in turn will have full accountability and authority to oversee all activities of the program at their site, in accordance with the management plan worked out in consultation with the advisory committee.

The detailed structure for the multi-site high elevation forest system program is illustrated in Figure 5. The purpose and operation of the individual components are described in preceding sections of this report.

As both government and university policies encourage interaction with small business at appropriate times, this Program should make every effort to do so. Cooperation with the appropriate small businesses offers this Program the opportunity to interact with a wider range of scientists and technicians. Three areas of this Program seem appropriate for such interaction: 1) Meteorology/Climatology, 2) data base management, and 3) instrumentation. Traditionally, these areas have been well developed in the private sector and could offer substantial support to this research effort.

All parts in the structure of this Program are intended to fulfill its goals, and the ultimate responsibility of the Management and Assessment Center to ensure that they do so, from both technical and fiscal point of view. It thus becomes the Center's responsibility to represent the Program and its results, together with assessment of the Program's effectiveness, to sponsoring agencies.

## SECTION 10

## COST ESTIMATE FOR THE RECOMMENDED STUDY ON ATMOSPHERIC DEPOSITION AND ITS IMPACT ON HIGH ELEVATION MOUNTAIN FOREST SYSTEMS

- Cloud Chemistry Research and Monitoring Sites
  a. research sites (total of 3 are recommended at this time)
  b. monitoring sites (total of 3 are recommended at this time)
  c. research flights
- Meteorological and Climatological Documentation for all sites
- Analytical Measurement Laboratory (one centralized facility for all sites)
- Data Management and Quality Control (one office for all sites)
- Data Documentation and Distribution Office (one office for all sites)
- Academic Exchange and Minority Program (one office coordinating the activities for all sites)
- Center for Advanced Instrumentation Technology (one central facility serving all sites)
- Advisory Committee
- Management and Assessment Center
  See Table 4 for the management structure.

TABLE 4. RECOMMENDED MANAGEMENT STRUCTURE FOR THE U.S. STUDY OF HIGH ELEVATION FOREST SYSTEMS

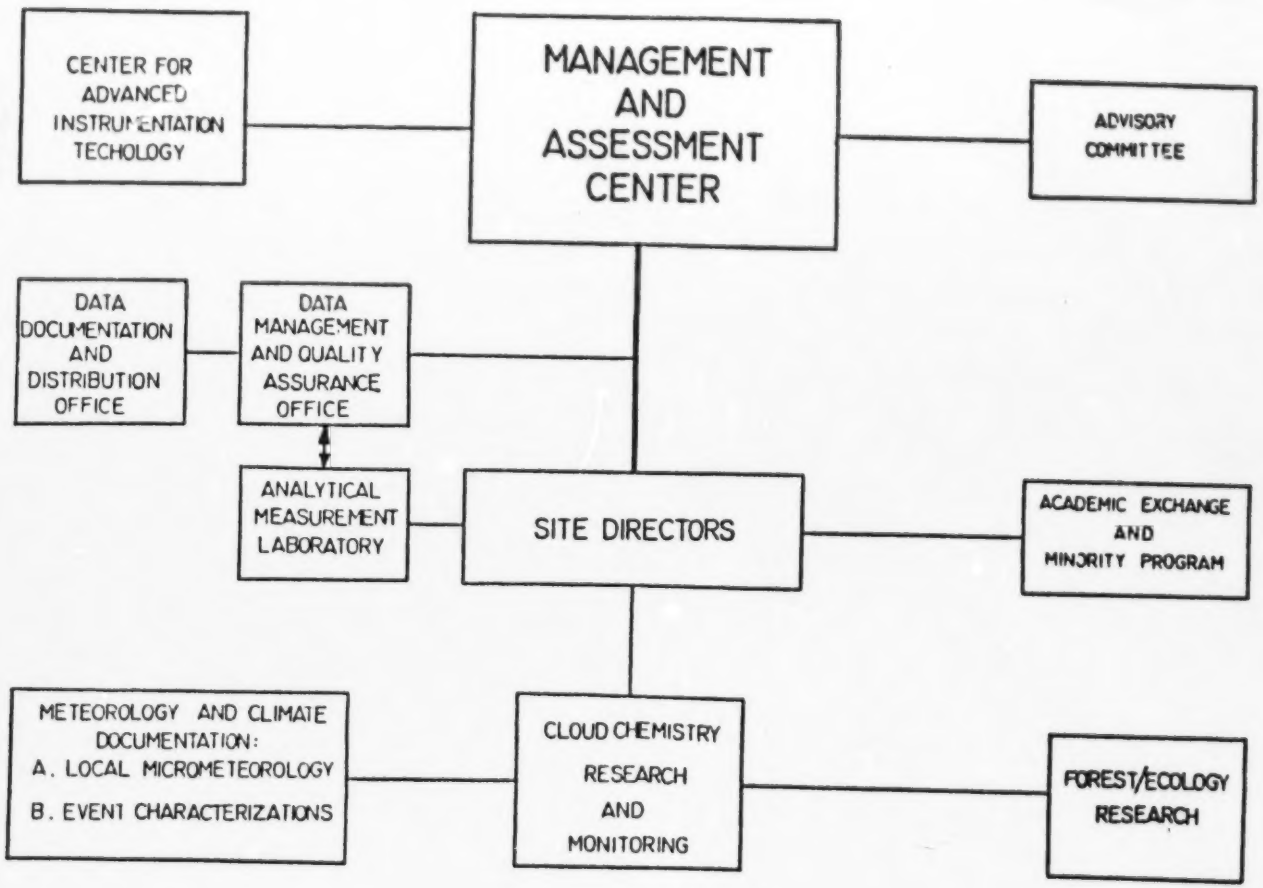

TABLE 5. ITEMIZED BUDGET

The projected costs for activities discussed in the text are presented in this table. These costs have been itemized as initial costs (to equip the field sites and research centers); personnel costs; ongoing operations costs (primarily supplies, equipment, travel and maintenance); and costs for services. These cost estimates do not include fringe benefits and indirect cost (overhead).

| Activity | Initial Capital Equipment | Initial Site Modification | Initial Meteorological Equipment | Continuous Annual Cost for Personnel | Continuous Annual Cost for Maintenance, Supply, Travel, Equipment | Continuous Annual Cost for Services |
|---|---|---|---|---|---|---|
| • Research Site (per site) | 300K | 80K | 200K | 230K<br>1 site director<br>1 scientist<br>1 chemist<br>5 technicians | 200K | |
| • Monitoring Site (per site) | 150K | 80K | 80K | 130K<br>1 site director<br>1 chemist<br>3 technicians | 100K | |
| • Meteorology and Climate | 60K | | | 80K<br>1 meteorologist<br>1 technician<br>1 analyst | 50K | |
| • Analytical Measurement Laboratory | | | | | | 400K |

TABLE 5 (Continued)

| Activity | Initial Capital Equipment | Initial Site Modification | Initial Meteorological Equipment | Continuous Annual Cost for Personnel | Continuous Annual Cost for Maintenance, Supply, Travel, Equipment | Continuous Annual Cost for Services |
|---|---|---|---|---|---|---|
| • Data Management | 50K | | | 120K<br>1 programmer<br>2 scientists | 80K | |
| • Data Documentation | 40K | | | 70K<br>1 programmer<br>1 analyst | 50K | |
| • Academic Exchange | | | | | 90K | |
| • Center for Instrument Technology | 320K | | | 150K<br>1 electronic engineer/director<br>2 electronic technicians<br>1 analytical chemist<br>1 graduate student | 50K | |
| • Advisory Committee | | | | | 15K | 25K<br>Honorarium $240/day<br>10 days/year<br>10 members |

TABLE 5 (Continued)

| Activity | Initial Capital Equipment | Initial Site Modification | Initial Meteorological Equipment | Continuous Annual Cost for Personnel | Continuous Annual Cost for Maintenance, Supply, Travel, Equipment | Continuous Annual Cost for Services |
|---|---|---|---|---|---|---|
| • Management and Assessment Center | 30K | | | 150K<br>1 director<br>1 administrative assistant<br>1 atmospheric chemist<br>1½ secretaries | 50K | |
| *TOTALS | $3.185 million | | | $1.65 million | $1.755 million | |

*Based on three "Research Sites" and three "Monitoring Sites"

It will require a period of up to two years before all recommended research and monitoring sites and the related support offices can be fully operational. We envision that the work will progress as is shown in Table 6. The percent of expenditure in the various categories (initial equipment, personnel and continuous supplies, equipment and services) reflects the build-up during the first two years until full operation (i.e., 100%) is achieved. A cost escalation factor for personnel and services has been included to more realistically reflect the anticipated annual cost over the next five years.

Table 7 shows the accumulated costs for each of the primary budget categories. These were calculated using the activity cost estimates in the preceding table, expended at the rates listed here. Fringe benefits and indirect cost (overhead) are not included. In this budget we have proposed the establishment of three research sites and three monitoring sites.

TABLE 6

RATE OF EXPENDITURES (Percent)

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| Initial equipment | 75% of $3.19 million | 25% | - | - | - |
| Personnel | 50% of $1.65 million | 80% | 115% | 120% | 125% |
| Supplies, equipment and services | 50% of $1.75 million | 75% | 110% | 115% | 120% |

TABLE 7

RATE OF EXPENDITURES (Millions)
(fringe benefits and overhead are not included)

| | | | | | |
|---|---|---|---|---|---|
| Initial equipment | $2.4 | $0.8 | - | - | - |
| Personnel | 0.8 | 1.3 | $1.9 | $2.0 | $2.1 |
| Supplies, equipment and services | 0.9 | 1.3 | 1.9 | 2.0 | 2.1 |
| TOTAL | $4.1 | $3.4 | $3.8 | $4.0 | $4.2 |

FRINGE BENEFITS AND INDIRECT COST

While costs vary widely among institutions, we have based the estimated total project costs on typical University fringe benefit and overhead rates. Equipment carries no overhead, neither in the initial equipment category nor in the continuing operation category. Fringe benefits were applied to salaries only, and overhead to everything except equipment.

TABLE 8. FINAL BUDGET ESTIMATE

Assume fringe benefits = 30%

Assume indirect cost (excluding equipment) = 50%

Budget Summary (in millions of dollars)

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| Initial equipment | $2.4 | $0.8 | - | - | - |
| Personnel | 1.6 | 2.6 | $3.7 | $3.9 | $4.0 |
| Supplies, equipment | 1.2 | 1.8 | 2.6 | 2.7 | 2.8 |
| services | | | | | |
| TOTAL | $5.2 | $5.2 | $6.3 | $6.6 | $6.8 |

Conclusion

The overall cost for the initiation and maintenance of a post study on atmospheric deposition and its impact on high elevation mountain forest systems will be of the order of 5-7 million dollars per year in 1984 dollars for the first five years of operation.

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Johnson, A.H., personal communication, 1984.

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## APPENDIX B

Comment on the ASRC Draft Workshop Report from Professor William E. Reifsnyder, Coordinator, Forest Meteorology Project, NOAA/ERL, June 7, 1984

**UNITED STATES DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303

June 7, 1984

.R/E/AR5:WER

Dr. Volker A. Mohnen
Director, ASRC
100 Fuller Road
Albany, N.Y. 12205

Dear Dr. Mohnen:

I am enclosing a brief statement of my views on the need for increased cooperation between the atmospheric science community and the forest science/forest meteorology community with regard to the acid precipitation problem.

At your suggestion, I called Gene Likens who confirmed that he is planning a small conference of scientists this coming fall to stimulate this interdisciplinary dialogue. I offered to help in suggesting names of key scientists.

I appreciate this opportunity to participate in the activity you have gotten going and offer my assistance, if I can be of help.

Sincerely yours,

William E. Reifsnyder, Coordinator
Forest Meteorology Project

# An Approach to Considering the Acid Deposition/Forest Damage Problem

William E. Reifsnyder
Yale University
NOAA/Environmental Research Laboratories

The biosphere is both a source and sink for numerous chemical species of physiological or pathological importance. The deposition of acidic particles and droplets on a biospheric surface and the transfer of gases from atmosphere to plant can only be pathologically significant if the active chemical species reaches the cellular site of biological activity in sufficient quantity or concentration to cause damage. For materials deposited on or diffusing to plant leaves, most of this transfer must be through the stomata. Soil and root processes probably require that chemical species enter the soil as solutes, although gaseous diffusion may play some part. In either case, the transfer is governed by poorly-understood processes of turbulent transport and diffusion; deposition, rebound and resuspension of particles; molecular forces and motions; and molecular diffusion, among other processes.

Unfortunately, it is still not clear how, even if, acid deposition in nature affects tree physiology and growth. Although correlations between acidic deposition and forest damage appear to be compelling, causal mechanisms and pathways remain elusive and undemonstrated. It is imperative, therefore, that any assessment of the "acid deposition problem" include in-depth analyses of what is known and what is not known concerning causal mechanisms of tree damage and the probable pathways by which atmospheric constituents enter the plant.

To illustrate the importance of better understanding these mechanisms we can make use of a simple scheme that considers nature and society as two protagonists. Suppose that either acid precipitation is or is not the cause of forest dieback. Further suppose that society has two options: either reduce acid precipitation through control of its precursors at the source; or do nothing to control emissions. Society's payoff matrix (in simplified form) can be expressed as:

PAYOFF MATRIX FOR SOCIETY

| Society's action / Nature | Control emissions of acid precip. precursors | No emission control |
|---|---|---|
| Precursor emissions cause of forest damage | A<br>0 | B<br>- |
| Precursor emissions not cause of forest damage | C<br>- | D<br>+ |

I assume that if acid precipitation is the cause of forest damage, and if society engages in a large-scale emission control effort, the payoff is zero, i.e., the cost of control will equal the saving in damage reduction. (It is not important for purposes of this argument whether the payoff is zero, positive, or negative. It is the relative payoffs that are important.) This is represented by box A in the figure.

If indeed, acid precipitation from anthropogenic sources is causing forest damage and society does nothing, society sustains the cost of the damage. The payoff to society is negative (box B). If anthropogenic acid precipitation is not the cause of forest damage, expensive control efforts with no resulting reduction in forest damage will also create a negative payoff (box C).

On the other hand, if anthropogenic sources are not the cause of forest damage, and if society does not control emissions, the payoff to society is positive relative to all other combinations (box D).

In order to use such a payoff matrix in the decision-making process, we need to know the degree of certainty that attaches to the acid/damage relationship. If, for example, we know with absolute certainty that there is a cause-and-effect relationship, and can predict the amount of damage for various levels of anthropogenic emission, then we can establish the optimum level of control effort and expenditure. On the other hand, if we know that acidic emissions are not related to forest damage, the optimum strategy is to expend no effort on emission control.

In the real world, uncertainty prevails; and decisions are not so easy. Nevertheless we can use the payoff matrix as a guide to decision making; and, perhaps even more importantly, as a guide for apportioning research efforts. Since so much depends on the degree of certainty with which we know the cause-and-effect relationships (consider the billions of dollars for control efforts versus billions of dollars of potential loss in forest value), it is evident that substantial expenditures for research are warranted. It is also evident that decisions for action should be made with clear knowledge of the uncertainties involved.

Another point must be made here. If we believe that the acid/damage relationship is known with certainty and if we discontinue searching for other causes, we may be unpleasantly surprised if the cause(s) of forest damage turn out to be something else. Not only have we been thus disposed to make irrelevant decisions concerning control of effluents, but we will have also lost valuable time in searching for the real causes of the forest decline.

Thus it is imperative that forest scientists and atmospheric scientists join in a vigorous effort to elucidate the complex web of biometeorological processes involved in the acid-deposition/forest-damage syndrome.

Finally, it should be noted that this kind of analysis could include many of the factors that have been ignored such as damage to other parts of the biosphere, material damage, and so forth. Also, society may wish to commit some portion of its resources into activities that produce intangible benefits, such as preserving natural ecosystems for future generations, or maintaining

pristine air so that its aesthetic qualities can be enjoyed by the present generation. These may be valid reasons for decision-making. The point to be made is that society should recognize the basis for its decisions and actions; and should attempt to make its decision as rational as possible.

## APPENDIX C

Comments on the ASRC Draft Workshop Report from Dr. Carmen M. Benkovitz, Atmospheric Sciences Division, Brookhaven National Laboratory, May 23, 1984

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
Upton, Long Island, New York 11973

Department of Applied Science

(516) 282-4135
FTS 666-

DATE: May 23, 1984

TO: V. Mohnen

FROM: C.M. Benkovitz (Signature on file)

SUBJECT: BNL Approach to the Implementation of a Data Management Function for the Atmospheric Deposition and Its Impact on High Elevation Mountain Forest Systems

At your request, I have reviewed the report titled "EPA/NSF Workshop on Atmospheric Deposition and Its Impact on High Elevation Mountain Forest Systems," ASRC Publication No. 981. As you know, our group in the Atmospheric Sciences Division at BNL has had extensive experience in the design and implementation of the data management functions for several large environmental studies. This memo contains our initial thoughts on the approach we would follow to implement a data management function for the project outlined in this ASRC publication. If desired, a more detailed proposal could be developed at a later date.

For a project of this magnitude and complexity, the data management function must be an integral part of the project management structure. The development of this function should start as soon as any part of the project is started. The data management team leaders should participate in all discussions pertaining to the development of the project, and should be kept fully cognizant of all facets of the project. This will facilitate the early identification of the project's needs in the data management area and can optimize the interfacing of data flow among the different parts of a very complex project.

The initial task of the data management team will be the identification of the functions to be performed by the data management activities. Project needs in the areas of data input, validation, analysis, distribution, reporting and archiving have to be properly identified. The coordination of data flow between project components must be detailed and appropriate interfaces agreeded upon. Existing data processing facilities that could be used by this project will be identified and studied. A prioritized list of tasks needed to implement the identified data management functions will be developed and, were feasible, level of resources will be included.

Based on the results of the previous task, the design and implementation of the systems needed to support the data management function can be

undertaken. We at BNL have always advocated a phased, modular approach to the design and implementation tasks. Basic modules are identified, designed and implemented in order of priority so different subsystems can be brought on line as project needs require.

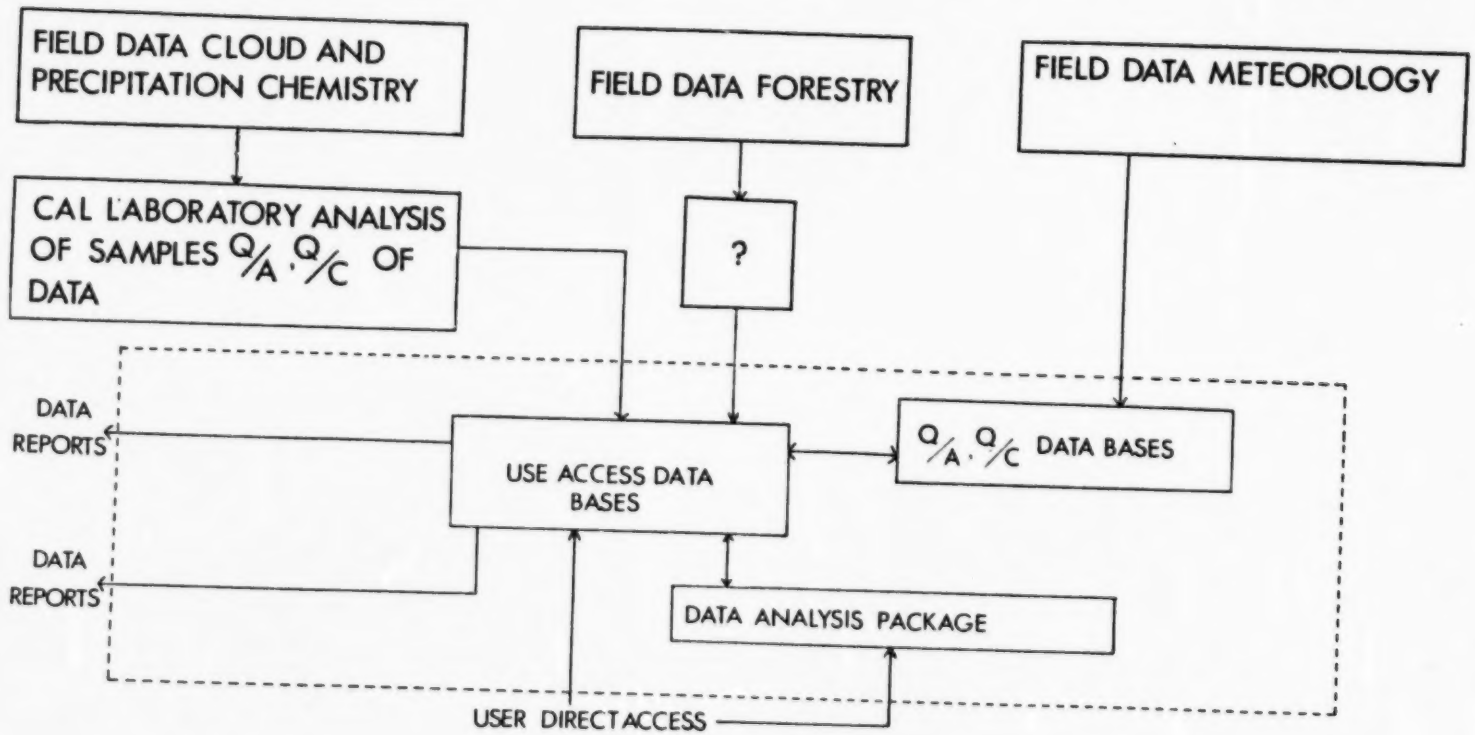
Figure 1 presents a schematic of project data flow as currently identified in the ASRC report. The implementation of a first-level data system for the project would include the design and implementation of the Q/A, Q/C system for processing the meteorological field data, the design and implementation of the user access data base(s), the design and implementation of the data flow from the CAL laboratory, the design and implementation of a basic set of data reports and data transfer formats and the design and implementation of the data flow (and possibly the Q/A Q/C system) for the forestry field data. Additional capabilities for data transfer, data analysis and user direct access can build upon this first-level system as the project progresses and resources become available.

It is difficult at this point to estimate resources needed since the magnitude and scope of the project have not been completely defined. A "ball park" estimate would allow 1 man year/year plus computer costs for the data management function definition phase, to be augmented to 2 man years/year and additional computer costs for the design and implementation phase. Once the data system enters a maintenance phase 1 man year/year plus computer costs would assure a continued coordination function and the smooth running of the data system. If additional facilities are to be implemented in the data system, periodic augmentation of available resources would be needed.

BNL is currently participating in several environmental programs which include the compilation of data bases that could complement the data to be developed by this program. Examples are the precipitation chemistry networks data base supported under the EPA Data Management for Atmospheric Processes (see enclosed summary write-up) and the air quality networks data base being compiled under DOE support, Task Group I of the NAPAP[1] program.

enc.
CMB/k
cc: P. Michael
B. Manowitz

[1]NAPAP=National Acid Precipitation Assessment Program


FIELD DATA CLOUD AND PRECIPITATION CHEMISTRY
FIELD DATA FORESTRY
FIELD DATA METEOROLOGY
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Q/A, Q/C DATA BASES
DATA REPORTS
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USER DIRECT ACCESS

Figure 1.

# APPENDIX D

## Critical Comments and Responses

No dissenting views have been submitted to the workshop chairman by either workshop participants or reviewers. The responses submitted by Dr. Carmen Benkovitz of the Brookhaven National Laboratory and Professor W. Reifsnyder of Yale University were both very helpful and to the point.

Dr. Benkovitz's suggestions have been included in this final report, with her approval. The problem addressed by Professor Reifsnyder is being addressed by a special workshop that will be held sometime at the end of 1984 at the New York Botanical Garden. Professor Likens will be able to host a meeting of forest ecologists, soil ecologists and meteorologists at his institute <u>if</u> it is organized by some other person. This workshop chairman recognizes the great need that such a meeting be held as soon as possible and is willing to take on the responsibility of organizing such a meeting. The workshop chairman has brought this problem to the attention of Dr. David Slade of the Department of Energy who has shown considerable interest in organizing a "Fort Lauderdale type" workshop, bringing together forest and soil scientists with atmospheric chemists and meteorologists.

**The New York Botanical Garden**
**Institute of Ecosystem Studies**

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Director
Gene E. Likens

8 August 1984

Dr. Volker A. Mohnen
Director
Atmospheric Sciences Research Center
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1400 Washington Avenue
Albany, New York 12222

Dear Volker:

On reflection about your phone call yesterday and on reading your letter to David Slade (1 August 1984), I would like to clarify one point. I am happy to host a meeting of forest ecologists, soil ecologists, and meteorologists here at the Institute this fall, but unfortunately do not have time to organize such a meeting. I could "help" to organize the meeting, but my schedule is just too hectic right now to take on the responsibility for making the contacts and arrangements for such a meeting. Possibly Dudley Raynal or Jon Scott would be willing to do it.

With best regards.

Sincerely,

Gene E. Likens
Director

GEL/jbc

APPENDIX E

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